International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 12, Issue 1, Feb 2022, 79–88

ESTIMATING THE IMPACT FORCES AND OPERATING FORCES IN A LATHE TOOL USING INVERSE FINITE ELEMENT APPROACH

MANJUNATH GOWDA. M. R[1], KIRAN GOWDA M.R[2], ARJUN M[3] & IRFAN .G[4]

[1]Professor, Department of Mechanical Engineering, H.M.S.I.T, [2]AssistantProfessor, Department of Mechanical Engineering, C.I.T, [3]AssistantProfessor, Department of Mechanical Engineering, H.M.S.I.T, [4]Professor, Department of Mechanical Engineering, H.M.S.I.T, Tumkur, Karnataka, India

ABSTRACT

Inverse FEM is a technique based on the loading force identification method of the Finite element. Charging approaches are based on the reverse finding problem approach. Linear, as well as non-linear system methods, are formulated based on the minimization of assumed objective functions. The least square error is primarily used as an analytical feature between the virtual and calculated device responses.

The inverse finite element method is a hybrid numerical and experimental method to determine operating forces precisely. Mechanical members may not be designed considering the extreme cutting forces. Hence the problem is taken to identify the cutting forces of a cutting lathe tool during turning operation using inverse FEM technique. Strain gauges are mounted on a lathe tool near the fixed end locations to measure the strains during turning operation.

Lab view are called virtual instruments is used to evaluate the impact forces on a Lathe tool. The Lab view includes a wide range of tools to evaluate, monitor and store data and tools to help you repair the coding. The turning is carried out with the instrument and strains are measured at different speeds at known locations. The determined stresses of a device are compared by a least square approach with the empirical strains.

Studies have been carried out to determine impact forces using a Lathe tool employing Inverse FEM. This method is subsequently employed in the determination of cutting force during turning operation. Inverse FEM with strain gauge as sensors is used for estimating the cutting force for different speeds and for a speed of 250 rpm the cutting force estimated was 225.63N. The same force has been measured using a lathe tool dynamometer and measurement of force has found to an error of 15%. It is found that for higher speeds the error in measurement is reduced. i.e. at higher speeds, the vibrations are less and steady state is reached.

The cutting force estimated by inverse Fem using strain gauge as sensors is compared with the force measured using lathe tool dynamometer. The error in measurement is found to be 15%. This is observed to reduce as the speed increases. During this study Inverse finite element approach is applied for estimating the impact forces on cantilever beam and operating forces in a lathe.

KEYWORDS: Inverse FEM, Strain Gauges, Lab View, Least Square Approach, Impact Force.

Received: Jan 07, 2022; **Accepted**: Jan 27, 2022; **Published**: Feb 07, 2022; **Paper Id.**: IJMPERDFEB202206

Original Article

INTRODUCTION

For the performance of certain tasks, structural members and machines are designed and developed. They are especially constructed on the basis of loads and boundary conditions taking into account the material's properties.

Static load

Static loading Static load does not change with time. These are loads that progressively increase over time or have

insignificant dynamic effects. Since static loads are much easier for structural analysis than dynamic ones, construction codes usually require statically-equivalent loads for wind, traffic or earthquake dynamic loads.

Dynamic load

The dynamic load changes over time. If this changes gradually, the response of the system can be calculated by static analysis but if the response changes quickly, then the dynamic analysis will decide the response. Because the system cannot respond to loading rapidly, a dynamic load can have a significantly greater impact than a static load of the same magnitude. Significant dynamic effects show dynamic loads. E.g. impact loads tides, wind gusts and extreme earthquakes.

Inverse FEM

Inverse FEM is a technique based on the loading force identification method of the Finite element. Charging approaches are based on the reverse finding problem approach. A number of approaches have been developed for the linear system in this field. Linear, as well as non-linear system methods, are formulated based on the minimization of assumed objective functions. The least square error is primarily used as an analytical feature between the virtual and calculated device responses. The identification of model parameters is crucial for different algorithms for resolving reverse problems such as the identification of Force. Rapid numerical device creation and computer technology growth make Inverse FEM possible.

General Procedure of Solving an Inverse Problem

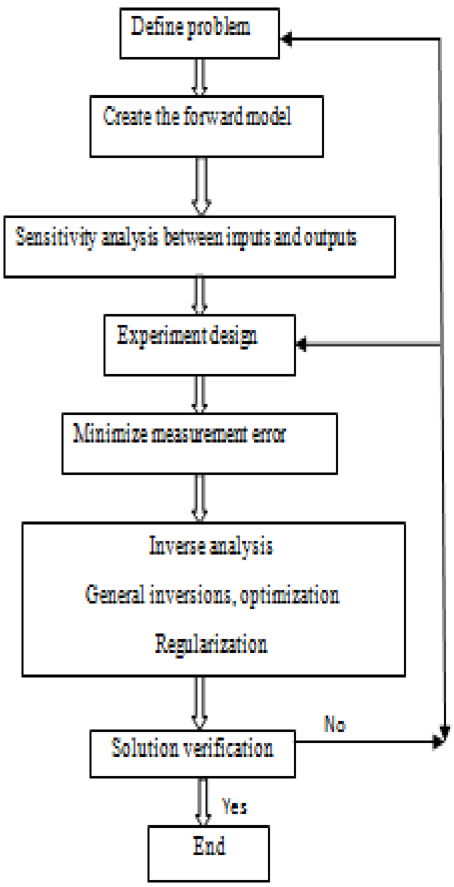
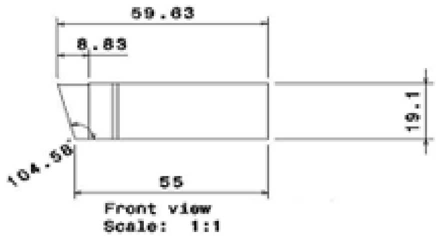
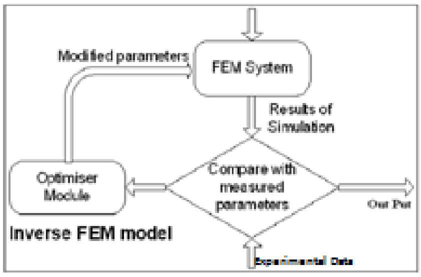


Figure1: Flow Chart to Solve Inverse problems

STATEMENT OF PROBLEM

Application Problem on Lathe Tool





Mechanical members may not be designed considering the extreme cutting forces. Hence the problem is taken to identify the cutting forces during turning operation using the inverse FEM technique. As we know lathe tool acts as a cantilever beam. The inverse identification problem on cutting lathe tools is carried out in the laboratory.

A model of a cutting lathe tool from industrial application is considered for our laboratory experimental work. Strain gauges are mounted on a lathe tool near the fixed end locations to measure the strains during turning operation.

MATHEMATICAL THEORY ON INVERSE PROBLEM

Formulation and Solution of Inverse Problems

General Inversion of System Matrix

Consider a system whose forward problem can be formulated as Equation 3.2. For the calculation of input X, the solution to the related inverse question can be sought.

$$X^{e}_{NX1} = S^{-g}_{NXM} Y^{m}_{MX1} \tag{1}$$

Where the superscripts ' e' and' m' are respectively the value calculated and determined. The output vector Y is now known as the device results obtained by means of regular measurements, documents or observations, and S is an opposite of matrix S generated by using Equation 3.31.

- Under-posed problems - when M < N
- Even-posed problems- when M = N
- Over-posed problems - when M > N

The following section describes the way in which these reverse problems are solved. While assuming that S can be obtained and thus X can be calculated by using Equation 3.31. The quality of the prediction following the reversal must be checked. Production Y can be calculated with approximate X, based on the forward Equation 3.2 formula.

$$Y^{p}_{Mx1} = S_{MXN} X^{e}_{Nx1} = \left[S_{MxN} S^{-g}_{NXM} \right] Y^{m}_{MX1} \tag{2}$$

This equation clearly shows that, if

$$\left[S_{MXN} S^{-g}_{NXM} \right] = I \tag{3}$$

Where I am a matrix marker, calculation data can be repeated by the reverse process. When a S-g obtained does

not satisfy Eq 3.33, it will not replicate the measurement results. The matrix

$$R_{o(MXN)} = \left[S_{MXN} S_{NXM}^{-g} \right] \tag{4}$$

Therefore, defined as the matrix of reproductivity output. In terms of reproducing input or output data, the computer Ro may give an indication for the accuracy of an inverse operation. If Ro= I, the reversal is replicable. Next, the real X is claimed to fulfill the forward formula for the measured Y obtained for the actual event:

$$Y_{MX1}^{P} = S_{MXN} X_{NX1}^{t} \tag{5}$$

Where the superscript t stands for the true values. Substituting this equation into equation 3.31 gives,

$$X_{NX1}^{e} = \left[S_{NXM}^{-g} S_{MXN} \right] X_{NX1}^{t} \tag{6}$$

The preceding equation clearly shows that, if

$$\left[S_{NXM}^{-g} S_{MXN} \right] = \mathrm{I} \tag{7}$$

The inverse procedure can provide the exact estimation of the inputs. Therefore, the matrix

$$R_{I(NXN)} = \left[S_{NXM}^{-g} S_{MXN} \right] \tag{8}$$

Is defined as an input reproducibility matrix. Computing R_I can give an indication of the quality of an inverse procedure in terms of estimating the input of the system.

Under-Posed Problems: Minimum Length Solution

If M is less than the estimated number of unknowns for the system, then it is a fundamental problem. There is an infinite number of solutions to the underlying problem that follow the exact equation without the defect of the accompanying forward model.

Even-Posed Problems: Standard Inversion of Matrix

If the number of known results is equal to N, the problem is even and the device matrix SN x N square matrix with rows an d columns of N is the same. The unknown number is calculated for the program. The machine has the same number.

Over-Posed Problems: Least-Squares Solution

If M, which is larger than the unknown unit, N, the calculated number of unknowns is over imposed. There can be a number of solutions to the problem of over position to satisfy certain right forward model equations. A solution which is physically significant and properly compromises all the equations of the future model, therefore, needs to be found. The "Lesser Squares" approach is a common method. The LS solution is formulated in the following way. DefineΠas a first function.

$$\Pi = (Y^{m} - SX)^{T} (Y^{m} - SX) \tag{9}$$

In addition, this is the L2 rule for the estimation and measurements of the forward model.

$$\frac{\partial \Pi}{\partial x} = 0 \tag{10}$$

$$\frac{\partial \Pi}{\partial x} = -2S^T\left(Y^m - SX\right) = 0 \tag{11}$$

Or

$$S^T Y^m = S^T S X \tag{12}$$

Consider the matrix $S^T S$ is symmetric as

$$(S^T S)^T + (S)^T (S^T)^T = S^T S \tag{13}$$

The approximate X can be calculated as if $S^T S$ were invertible.

$$X^e = [S^T S]^{-1} S^T Y^m \tag{14}$$

The definition of the generalized inverse matrix for the over-posed inverse problem is

$$S^{-g} = [S^T S]^{-1} S^T \tag{15}$$

The output reproducibility matrix is

$$R_0 = SS^{-g} = S\,[S^T S]^{-1} S^T \tag{16}$$

Usually, this cannot be a matrix of identity. Consequently, generally speaking, the LS solution will be reproducible. The reproducibility matrix of the input is, however,

$$R_I = S^{-g} S = [S^T S]^{-1} S^T S = I \tag{17}$$

This implies that the LS solution is input reproducible and gives the true estimation of the input of the system.

Lathe Tool model

Measurement of Cutting Force on a Lathe Tool

The turning is carried out with the instrument and strains are measured at different speeds at known locations. The determined stresses of a device are compared by a less square approach with the empirical strains.

Forward Analysis

The tool Lathe is Catia V5 modeled. For meshing the model, the element Solid45 is used. The meshed tool is simulated by limiting the whole D.O.F to one end of the tool in ANSYS as a cantilever strap and applying the statically loading range to the open end of the tool. Strain is documented at known places.

The material and geometrical properties are,

$E = 2.1\text{x}10^5 N/mm^2$; $\mu = 0.3$

$A = 238.177 mm^2$, $\rho = 7850e\text{-}09\ N/mm^3$

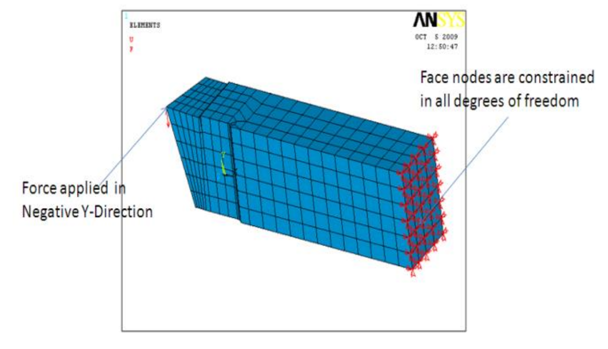


Figure 4: FE Model with Boundary Conditions

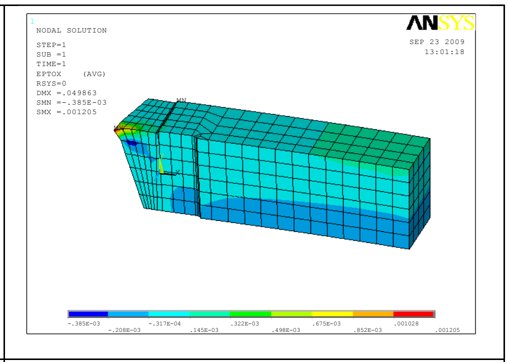


Figure 5: Strain Plot for Applied Force

ANSYS Strain Readings for Range of Static Load on Lathe Tool

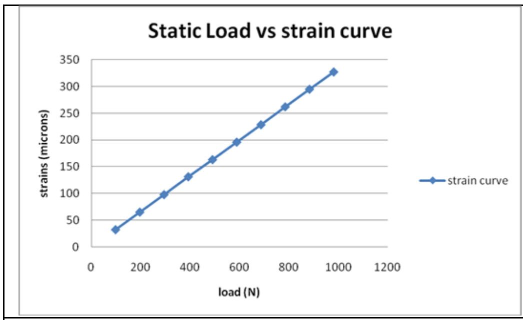


Figure 6: Static Loads vs. Strain Curve

EXPERIMENTAL MODEL

A cutting lathe tool is taken for experimentation in the laboratory and Strain gauges are mounted at predetermined points on the surface of the lathe tool. The cutting tool is operated on a lathe for different speeds by maintaining the constant depth of cut (1.5mm) and constant feed (0.12rev/min).

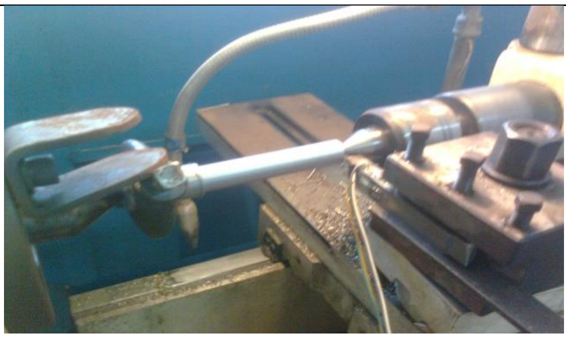
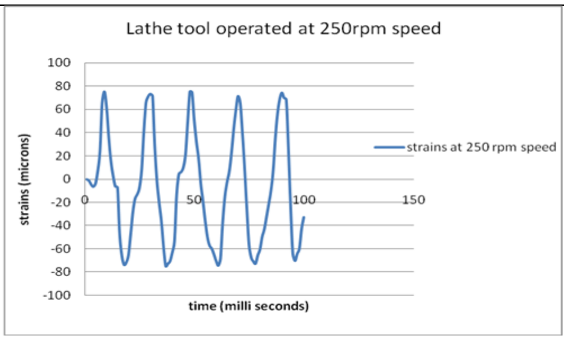


Figure 7: Location of Strain Gauge on Lathe Tool

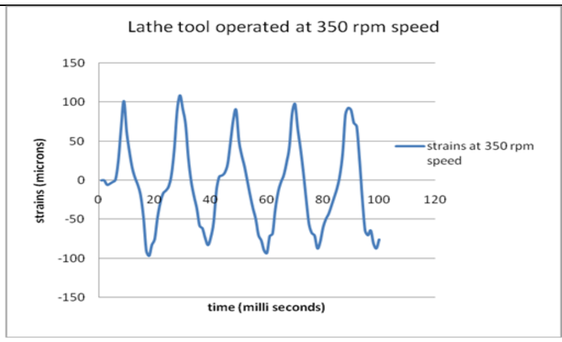
Figure 8: Experimental Set Up

Table 1: Experimental Strain Readings for Lathe Tool Operated at Different Speeds

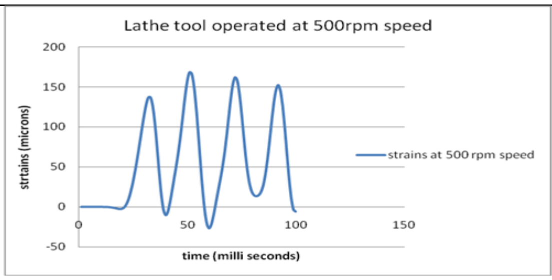
Speed (rpm)	Depth of cut (mm)	Feed (rev/min)	Max strain readings (microns)
250	1.5	0.12	75.47
350	1.5	0.12	108.5
500	1.5	0.12	168.5



Experimentally Measured Strain Readings at 250 Rpm



Experimentally Measured Strain Readings at 350 Rpm



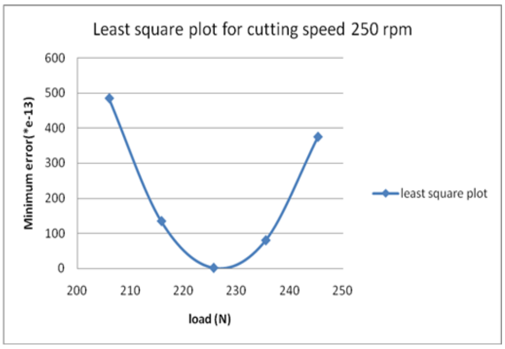
Experimentally Measured Strain Readings at 500 Rpm

Table 2:Least Square Error Readings for Cutting Speed 250 Rpm

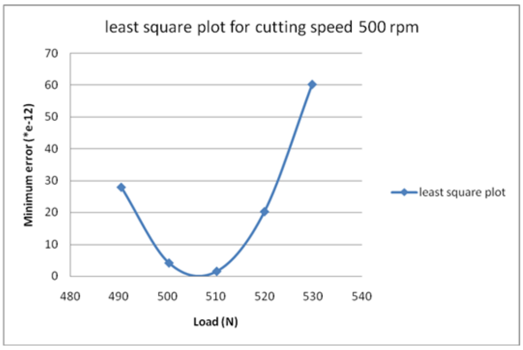
Load (N)	Ansys Strain (ϵ_A) (microns)	Exp Strain (ϵ_E)(microns)	Least square error (Minimum Error) =(Ansysstrain-Expstrain)^2 (*10e-13)
206.01	68.5	75.47	485
215.82	71.8	75.47	134.68
225.63	75.1	75.47	1.369
235.44	78.3	75.47	80.0
245.25	81.6	75.47	375

Table 3: Least Square Error Readings for Cutting Speed 500 Rpm

Load (N)	Ansys Strain (ϵ_A) (microns)	Exp Strain (ϵ_E) (microns)	Least square error (Minimum Error) =(Ansysstrain-Expstrain)^2 (*10e-12)
490.5	163.21	168.5	27.9
500.31	166.47	168.5	4.12
510.12	169.73	168.5	1.51
519.93	173.00	168.5	20.25
529.74	176.26	168.5	60.21



Plot of Least Square Difference for Cutting Speed 250 Rpm



Plot of Least Square Difference for Cutting Speed 500 Rpm

Table 4: Cutting Force Readings from Lathe Tool Dynamometer

Cutting Speed (rpm)	Depth of cut (mm)	Feed (rev/min)	Cutting Force (Newton)
250	1.5	0.12	264.87
350	1.5	0.12	372.78
500	1.5	0.12	549.36

Table 5: Comparison of Cutting Force from Inverse FEM and Tool Dynamometer

Cutting Speed (rpm)	Cutting Force Inverse FEM (Newton)	Cutting Force Tool dynamometer readings (Newton)	Error (%)
250	225.63	264.87	14.81
350	323.73	372.78	13.15
500	510.12	549.36	7.14

RESULTS AND DISCUSSIONS

Studies have been carried out to determine impact forces using a Lathe tool employing Inverse FEM. This method is subsequently employed in the determination of cutting force during turning operation. Following is the summary of the results obtained during this study.

Lathe Tool

The methodology developed above is applied for measuring force on a lathe tool during turning operation. Inverse FEM with strain gauge as sensors is used for estimating the cutting force for different speeds. Strain gauges are mounted on the cutting tool so as to measure the cutting forces in the vertical direction, and for a speed of 250 rpm the cutting force estimated was 225.63N. The same force has been measured using a lathe tool dynamometer and measurement of force has found to an error of 15%.

The experiment is repeated for different cutting speeds and it is found that for higher speeds the error in measurement is reduced. i.e. at higher speeds, the vibrations are less and steady state is reached.

CONCLUSION AND SCOPE FOR FUTURE WORK

For optimal design of the machine and structural members, it is necessary that the forces to which such members are

subjected to be known before the design process is started. But usually, the operating forces are not exactly known and design based on such approximate loads is not optimal. This shortcoming is overcome by employing the inverse finite element method. The inverse finite element method is a hybrid numerical and experimental method to determine operating forces precisely.

The method is extended to measure the cutting force in the lathe tool. The cutting force estimated by inverse Fem using strain gauge as sensors is compared with the force measured using lathe tool dynamometer. The error in measurement is found to be 15%. This is observed to reduce as the speed increases.

Thus, during this study Inverse finite element approach is applied for estimating the impact forces on cantilever beam and operating forces in a lathe.

Future Work

1. The work can also be extended to find the dynamic forces acting on the automobiles and machine parts.
2. The inverse method can also be carried out to find the Material property and Geometry identification.

REFERENCES

1. *Doyle, J.F., "Determining the contact force during the transverse impact of plates", Exp. Mech., 27(10), 68, 1987.*
2. *Yen, C.S. and Wu, E., "On the inverse problem of rectangular plates subjected to elastic impact", J. Appl. Mech., 62,692, 1995*
3. *Tadeusz Uhl "The inverse identification problem and its technical application" Arch Appl Mech(2006) DOI 10.1007/s00419-006-0086-9*
4. *Michael Sheehy, Jeff Punch, Brayn Rodgers " The response of a miniature scale cantilever beam to high-G-impact stimuli " proceedings of IMECE2006, Nov 05-10, 2006, Chicago, Illinois, USA*
5. *Philip P. Garland and Robert J. Rogers-"An experimental study of contact forces during oblique Elastic Impact" May-2009, vol 76/ 031015-1.*
6. *Dr: D.S.Chandrashekaraiah. Professor and Chairman (Retired), Dept of Mathematics. UVCE. Bangalore. "Engineering Mathematics". Part IV.*
7. *G.R.Liu and X.Han "computational inverse finite element method in Non destructive evaluation"*
8. *AHN, Kook Chan, and H. D. Kang. "Influence of Stacking Sequence and Nanoclay Content on Macroscopic Behaviour of Nanoclay/Epoxy Composites." Int. J. of Mechanical and Production Engineering Research and Development (IJMPERD), 9 (2) (2019): 549-554.*
9. *Kumar, Nitesh. "Thermal analysis of viscoelastic propellant grains with developed axisymmetric finite elements using Herrmann formulation." International Journal of Mechanical and Production Engineering Research and Development 8.6 (2018): 773-782.*
10. *Aru, Suraj, et al. "Design, analysis and optimization of a multi-tubular space frame." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P) (2014): 2249-6890.*
11. *Kang, H. D., and Kook Chan Ahn. "A study on the dynamic behaviour of the coating tempered glass plate under impact." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8.6 (2018): 193-200.*